SOME CHARACTERISTIC PROPERTIES OF COTTON-GIN EMISSIONS

ARS–S–4
APRIL 1973

SOUTHERN REGION

AGRICULTURAL RESEARCH SERVICE • U.S. DEPARTMENT OF AGRICULTURE

SOME CHARACTERISTIC PROPERTIES OF COTTON-GIN EMISSIONS

By Eugene P. Columbus and E. Dale Threadgill[1]

INTRODUCTION

The Federal Clean Air Act of 1963 was the major tool in implementing air pollution control. Before this law, many complaints were received from individuals and groups concerning industry's methods of disposing of waste products or other unwanted refuse, or both of these. Air pollution control has progressed quite rapidly since 1963 in all industries, including the cotton ginning industry. However, greater knowledge of the properties of the materials that constitute cotton-gin emissions is needed to enhance the development of improved emission abatement devices and to aid in the prediction of the pollution potential of these emissions in the area of cotton gins.

The cotton ginning process begins with a nonuniform material called seed cotton that is altered by the ginning process to become cottonseed and cotton fibers. Before, during, and after the seed is separated from the fibers, the material is subjected to several stages of cleaning. This cleaning is usually done mechanically and the cotton is transported by air between each machine. Although the major quantity of the trash is captured, at some point in the process the dust-laden air is allowed to escape into the atmosphere. The effluent allowed to escape travels with the prevailing winds and, until it comes to rest, becomes an air pollution problem.

The trash removed from the cotton during the ginning process is collected at several machines. This trash is of two distinct types. The first type, removed by the seed cotton cleaning machines, is composed mostly of comparatively large, heavy material that is easily removed. The second type usually consists of relatively fine and light material that is removed by the lint cleaners after the seed and fiber have been separated. The high-pressure air system is used to transport the seed cotton and its trash. The air from this system is usually cleaned by a cyclone that is a centrifugal force type of cleaner. The low-pressure air system transports the lint fibers and the finer trash from the lint cleaners. This air is generally cleaned by a screen-type filter such as an inline filter.[2] Some trash that is conveyed through the system is composed of very small particles that cannot be removed by the collection systems in the gin plant and, therefore, are exhausted into the atmosphere.

The tabulation that follows shows the percentages of the several types of trash found within both the seed cotton-cleaning system and the lint-cleaning system.[3]

Type of trash	*Percentage of trash removed*[1]
Hulls	1.20
Sticks and stems	.20
Leaf	2.15
Pin trash	.10
Motes	.25
Lint cleaner waste	.78
Total	4.68

[1]Percentage of trash removed from machine-picked cotton based on seed cotton weights and average crops 1969-70.

These percentages are all based on the incoming seed cotton weights. According to Wesley, McCaskill, and Columbus, the sizes of particles emitted from a cyclone handling typical gin

[1]Agricultural engineer, Stoneville Area, Southern Region, Agricultural Research Service, U.S. Department of Agriculture, Stoneville, Miss., and assistant professor, Agricultural and Biological Engineering Department, Mississippi State University, State College, Miss.

[2]Alberson, D. M., and Baker, R. V. An Inline Air filter for collecting Cotton Gin Condenser Air Pollutants. U.S. Dept. Agr., Agr. Res. Serv. ARS 42-103, September 1964.

[3]Shaw, Charles S. U.S. Department of Agriculture, ARS Cotton Ginning Research Laboratory. Stoneville, Miss. (Unpublished data.)

trash are 27 microns or less.[4] Alberson and Baker state that the dust not retained by the inline filter, which is a screen type, was less than 165 microns in diameter.[5] Therefore, based on these studies, particles less than 165 microns in diameter represent that part of the total gin trash that is a potential air pollutant.

OBJECTIVES

The objectives of this study were as follows:

1. Determine the particle size distribution of cotton gin emissions.
2. Determine terminal velocity, Reynolds number, and drag coefficient for each range of particle size.

PROCEDURES AND EQUIPMENT

Gin emissions examined under a microscope revealed that they consist of sand, quartz, small pieces of bark and leaves, short fibers, spores, and pollens. The complexity of the composition of this gin dust indicates inconsistency in the shape of the particulates that makes the determination of any property quite difficult.

The first step, therefore, was to determine the distribution of particle size and then fractionate enough material in each size range so that other physical properties could be determined. The gin dust was fractionated with an Allen-Bradley Sonic Sifter Model L3P,[6] according to the operating instructions of the instrument. The percentages by weight of all particles less than 150 microns in diameter that were found in the cotton gin effluents follow:

Range of particle size (Microns)	*Percent (by weight) of gin emissions*
75 to 150	1.81
60 to 75	.44
45 to 60	.40
30 to 45	.46
20 to 30	.28
20 or less	.12
Total	3.51

The figures are a percentage of the total trash listed in the tabulation on page 1, or 3.51 percent of the total trash.

To calculate terminal velocity, Reynolds number, and drag coefficient, an effective particle diameter was determined for each size class. Albertson found that the shape factor $c/(ab)^{1/2}$, where a, b, and c are mutually perpendicular axes, appears to be satisfactory as a single parameter to express shape.[7] However, as the particles get smaller the three axes must be measured with a microscope. Several slides of gin dust and numerous particles on each slide were examined and measured, and no consistent value of the ratio $c/(ab)^{1/2}$ was found. These ratios ranged from less than 0.5 to greater than 1.0; that is, the ratios indicated that the shape of the particles varied from highly elongated to near spherical. These results indicated that accurate determination of terminal velocities would have to be experimental.

To determine the terminal velocity, a drop chamber was constructed of plate glass, 6 in. by 6 in. by 6 ft., so that particle motion could be studied without the influence of outside air. This chamber was placed on a rubber pad and had a Plexiglas top that was equipped to hold one of the Allen-Bradley sieves. The purpose of the sieve was to break up any aggregates of particles before their introduction into the chamber (fig. 1). The Plexiglas top was also equipped with a spring-loaded plunger so that a constant "thump" could be applied to the top. This plunger caused a relatively constant quantity of particles to fall through the sieve into the chamber for each test run.

A method of timing the particles over a fixed distance as they fell through the chamber consisted of two identical circuits. A photocell was placed at the beginning and the end of a fixed distance to detect the falling particles as they passed through a beam of light placed 90° from the center line of each photocell. The particles reflected light into the cell causing it to have a decreased electrical resistance. Each photocell was placed in one leg of a wheatstone bridge that was excited with 225 volts d. c. The unbalanced bridge output voltage was put into an amplifier.

[4] Wesley, R. A., McCaskill, O. L., and Columbus, E. P. A Comparison and Evaluation of Performance of Two Small-Diameter Cyclones for Collecting Cotton Gin Waste. U.S. Dept. Agr., Agr. Res. Serv. ARS 42-167. January 1970.

[5] See reference listed in footnote 2.

[6] Mention of a proprietary product in this publication does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture and does not imply its approval by the Department to the exclusion of other products that may also be suitable.

[7] Albertson, N. L. Effect of Shape on the Fall Velocity of Gravel Particles. Proceedings of the Fifth Hydraulics Conference, 1952. Iowa University Studies, Engineering Bulletin, vol. 31-34.

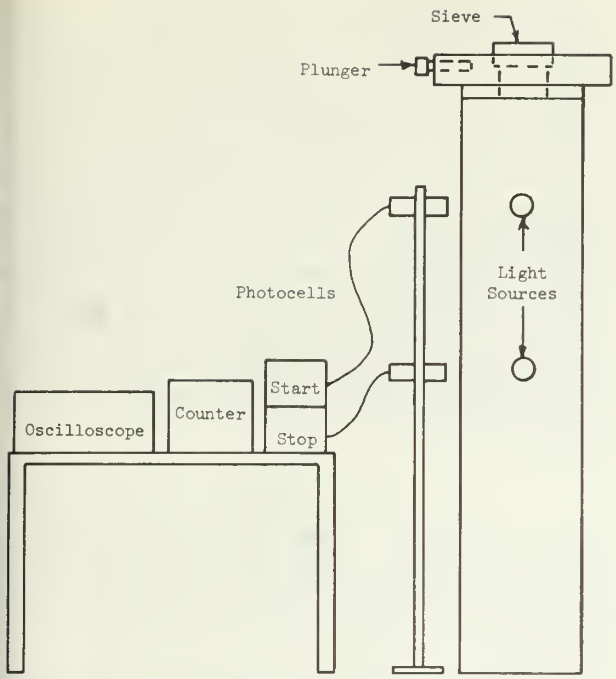

Figure 1.— Diagram of instruments and drop chamber used in terminal velocity determinations.

After amplification, the signal entered an electronic counter that started as the particles passed the first cell and stopped as they passed the second cell. The elapsed time was then divided into the known distance, thereby yielding a terminal velocity for the particles.

Particle size fell into several ranges, each of which had a different terminal velocity because of the difference in size. Table 1 contains the final results of the terminal velocity experiments; each experimental velocity represents an average of eight replications with 10 observations per replication, or an average of 80 observations. The 75 to 150 micron size range was omitted because of the large difference in particle size within this range. The terminal velocities are also shown in table 1 for comparison. They were calculated using Stokes' equation (assuming that the density of air is insignificant relative to the density of the particles):

$$v = \frac{D^2 g \rho}{18\,\mu}, \tag{1}$$

where v = terminal velocity of the particle,
ρ = particle density,
D = effective particle diameter,
g = acceleration due to gravity,
and μ = viscosity of air.

TABLE 1. – Terminal velocities for cotton gin dust

Range of particle size	Effective particle diameter	Experimental velocity	Stokes velocity
(Microns)	*Microns*	*Feet per second*	*Feet per second*
60 to 75	70	0.916	1.112
45 to 60	55	.673	.686
30 to 45	40	.409	.363
20 to 30	25	.225	.142
20 or more	20	.158	.091

Stokes' formula is based on the assumption that the particles are spheres. The gin-dust particles are not spheres and the density of the particles is not uniform; therefore, a bulk density was determined experimentally by immersing a known weight of the dust particles in a liquid measuring the displaced volume of liquid. The measured bulk density of 2.271 grams per cubic centimeter was used as the value of ρ in Stokes' equation. Since an effective particle diameter could not be calculated for gin dust, an effective particle diameter, shown in table 1, was assumed for each size class in Stokes' equation. Orr states that the shape and character of a surface influence the falling rate in such a way that irregular particles never attain the velocity of a sphere of equivalent weight.[8] The experimental velocities for the irregular particles are greater than the calculated Stokes' velocities for the lower three ranges. However, the velocities are for particles of equal density and equivalent diameter; that is not to say that the particles are of equivalent weight because the gin dust particles are rods and various other shapes that would mean that the gin-dust particles could be heavier and, therefore, have a greater terminal velocity.

The Reynolds numbers were calculated for each particle size range using the terminal velocity figures obtained experimentally and those calculated with Stokes' formula. The formula used to calculate the Reynolds numbers was:

$$R = D\rho_a v/\mu \tag{2}$$

where D = effective particle diameter,
ρ_a = density of the air,
v = terminal velocity of the particle,
and μ = viscosity of the air.

[8] Orr, Clyde, Jr. Particulate Technology. 1966. The Macmillan Company, New York, N.Y.

The values of the Reynolds number are shown in table 2.

To conduct any meaningful study of the motion of particles in the atmosphere, the relationship between Reynolds number and the drag coefficient is needed to calculate the drag forces acting upon the particles. The drag coefficient for a particle can be determined by utilizing the fact that the drag forces acting on a particle falling through air are equal to the viscous fluid forces acting on that particle.

The forces for a spherical particle are as follows:

$$F = 1/2 \rho_a V^2 C_D A \qquad (3a)$$

$$F_D = 3\pi\mu VD \qquad (3b)$$

where F = resistance force,
F_D = drag in a fluid for a spherical particle,
ρ_a = density of the air,
V = velocity of the air relative to the particle,
C_D = drag coefficient,
μ = viscosity of the air,
D = diameter of the particle,
and A = projected area normal to the direction of flow.

Equating these two equations and solving for the drag coefficient, C_D, of a spherical particle yields

$$C_D = \frac{6\pi\mu D}{\rho_a VA} \qquad (4)$$

Lapple indicates that this equation is often assumed to apply to irregular-shaped particles because of lack of appropriate descriptions of particle shape.[9] Assuming that this equation for spherical particles is applicable to gin-dust particles and using the assumed effective particle diameters and the experimentally determined terminal velocities, values of C_D can be calculated. Rather than use the assumed particle diameter to calculate an area for an equivalent spherical particle, the authors calculated the parameter of C_DA (product of drag coefficient and projected particle area) as shown in equation 5.

$$C_DA = \frac{6\pi\mu D}{\rho_a V} \qquad (5)$$

Also, values of C_DA were calculated for a sphere of the same density as gin dust for comparison. Values of C_DA are presented in table 2.

The values in table 2 show that, as expected, Reynolds numbers for gin-dust particles differ from those for spherical particles. Likewise, differences in values of C_DA for gin-dust particles relative to spherical particles are evident. This indicates that the behavior of cotton-gin dusts is quite different from that of spherical particles.

The deviations of values of terminal velocity and C_DA of gin dusts from Stokes' Law calculations are shown graphically in figures 2 and 3.

[9] Lapple, C. E. Fluid and Particle Mechanics. University of Delaware. Newark, Del. March 1956.

TABLE 2. —Reynolds numbers and drag coefficient-area (C_DA) for particles less than 75 microns

Range of particle size	Effective particle diameter	Experimental data[1] Reynolds No.	Experimental data[1] C_DA	Stokes' velocity data Reynolds No.	Stokes' velocity data C_DA
(Microns)	*Microns*		*Feet squared*		*Feet squared*
60 to 75	70	1.330	0.748×10^{-6}	1.614	0.617×10^{-6}
45 to 60	55	.768	$.800 \times 10^{-6}$	.782	$.785 \times 10^{-6}$
30 to 45	40	.339	$.958 \times 10^{-6}$	.279	1.079×10^{-6}
20 to 30	25	.117	1.088×10^{-6}	.074	1.724×10^{-6}
20 or less	20	.066	1.240×10^{-6}	.022	2.153×10^{-6}

[1] Reynolds numbers and drag coefficient-area values were calculated using experimental and calculated terminal velocities.

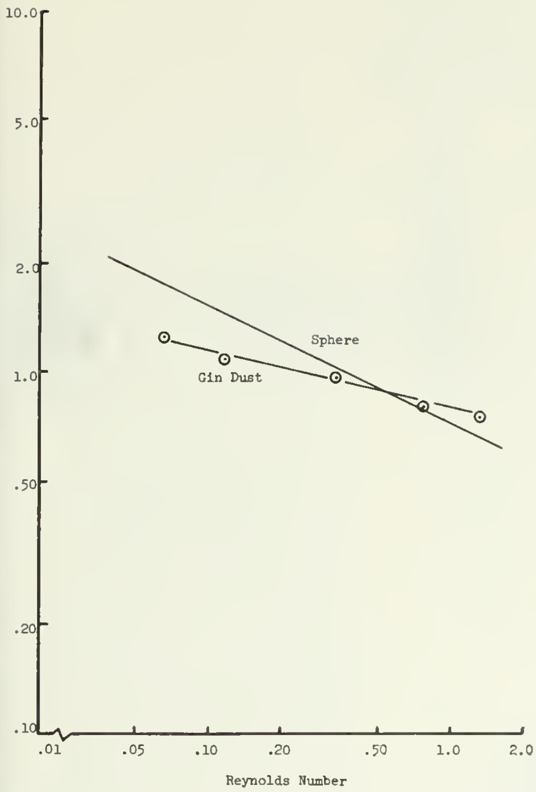

Figure 2. —C_DA versus Reynolds number for cotton-gin effluents smaller than 75 microns.

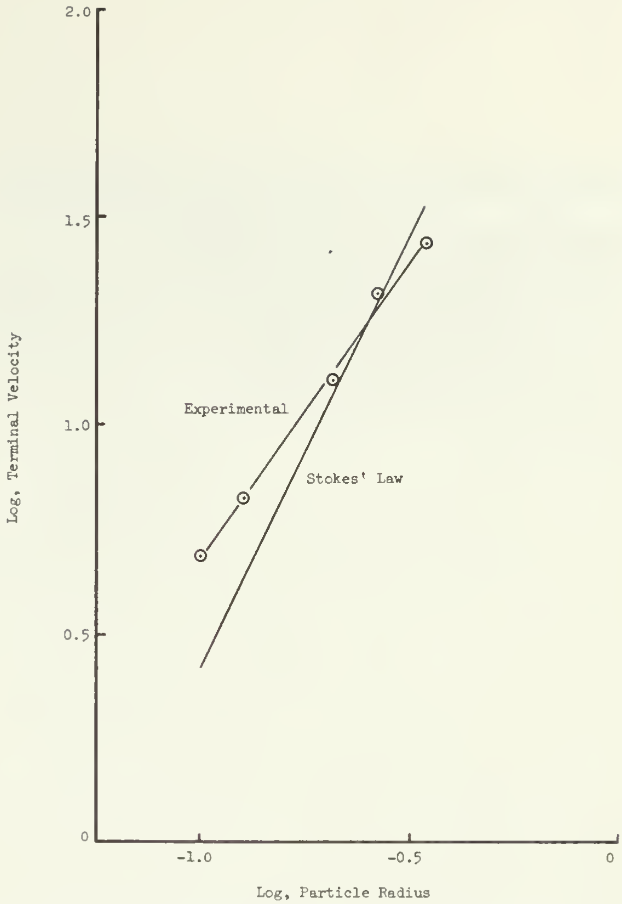

Figure 3. —Relationship between terminal velocity and effective particle radius.

SUMMARY

Tests were conducted to determine several properties of the cotton-gin emissions. The evaluation of these properties could lead to the design of more efficient abatement devices as well as an equation for predicting the pollution potential in the area around the cotton gin.

A review of literature showed that work had been conducted to express these same properties for spherical particles. The size distribution for the gin-dust particles ranged from 0.12 percent for particles less than 20 microns to 1.81 percent for the 75 to 150 micron particles. Terminal velocity measurements yielded values of 0.158 ft. per second for particles less than 20 microns to 0.916 ft. per second for the 60 to 75 micron particles. However, the dusts emitted from the cotton gins were established as irregular both in shape and composition. This study revealed that some properties of the gin dust are different from those of analogous spheres. Even though the values were not the same, the relative relationships of the properties, such as C_DA vs. R, were the same. That is, the plot of C_DA vs. R was an inverse logarithmic relationship for both the cotton-gin emissions and the spherical particles.

U. S. DEPARTMENT OF AGRICULTURE
AGRICULTURAL RESEARCH SERVICE
SOUTHERN REGION
P. O. BOX 53326
NEW ORLEANS, LOUISIANA 70153